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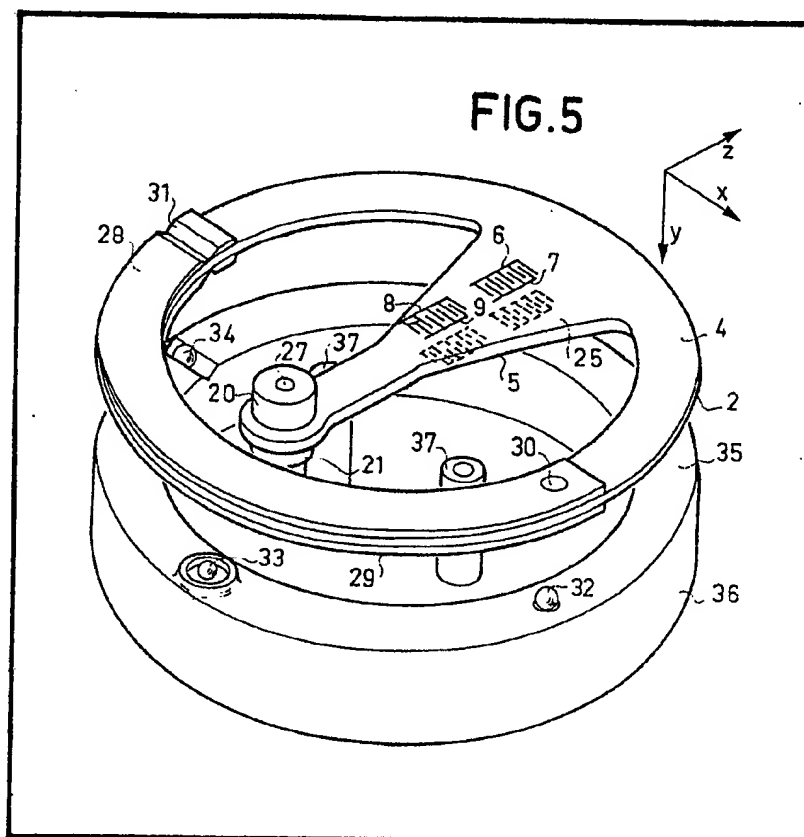
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(54) Elastic surface wave  
accelerometers

(57) In an elastic surface wave  
accelerometer comprising a bending

tongue cut out from a plate with  
parallel faces 2, the tongue comprises  
a zone of equal resistance to bending  
25 where elastic surface wave stress  
measuring means 6, 7, 8 and 9, are  
arranged along the faces 4 and 5.



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FIG. 1

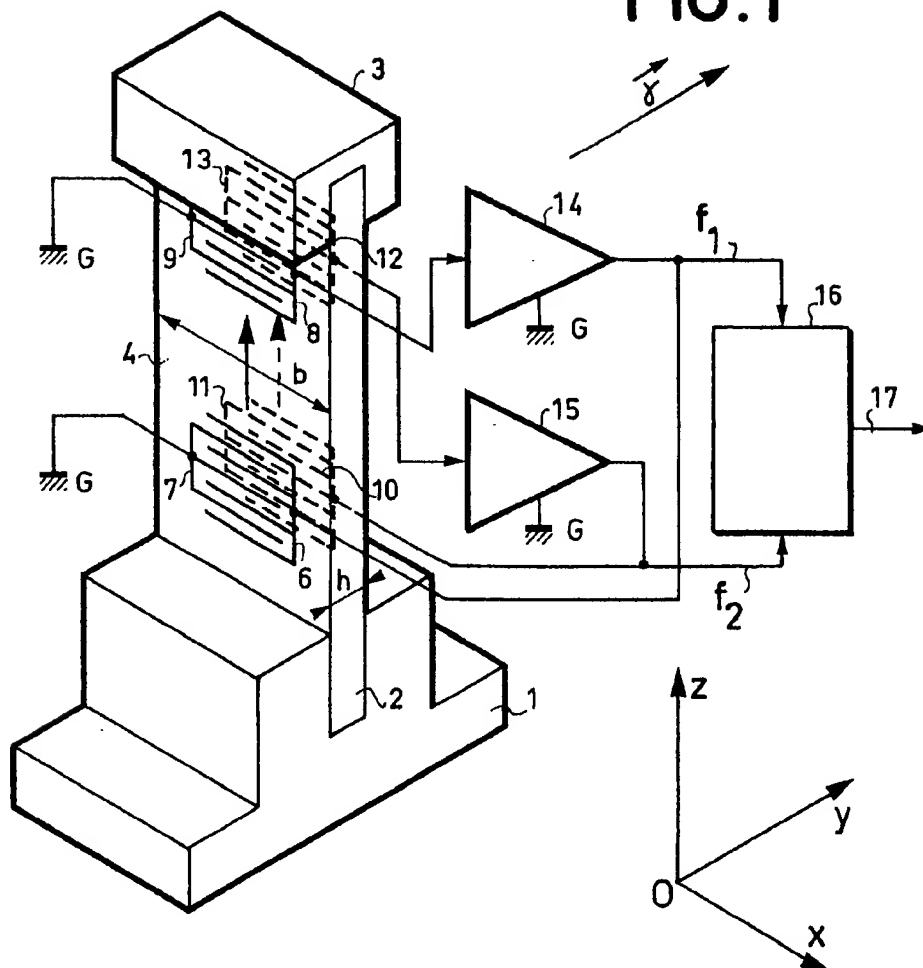
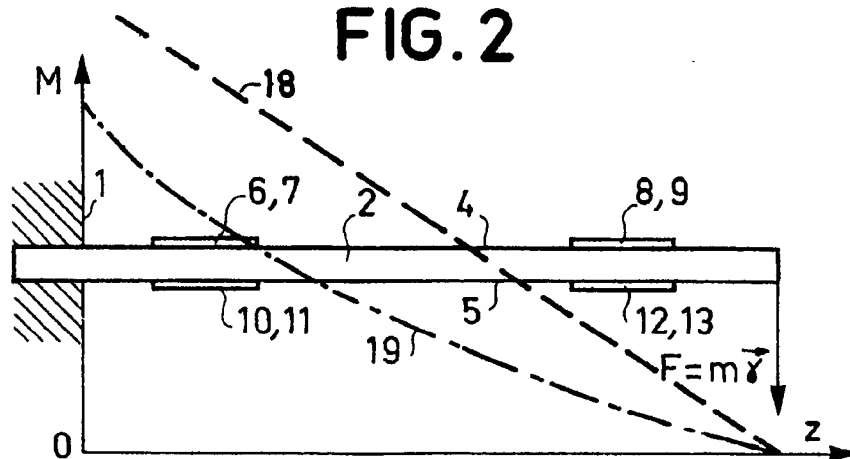


FIG. 2



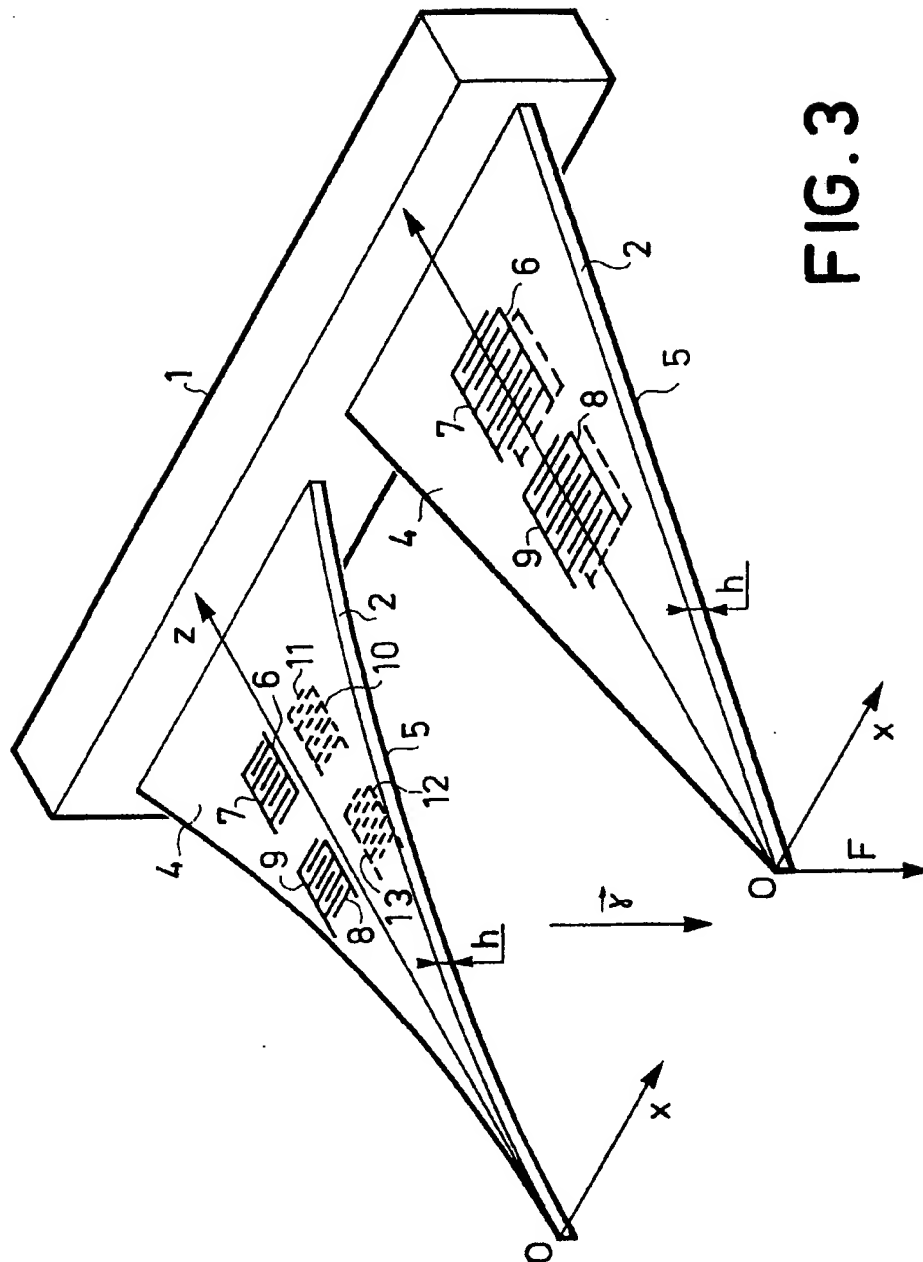


FIG. 3

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FIG. 4

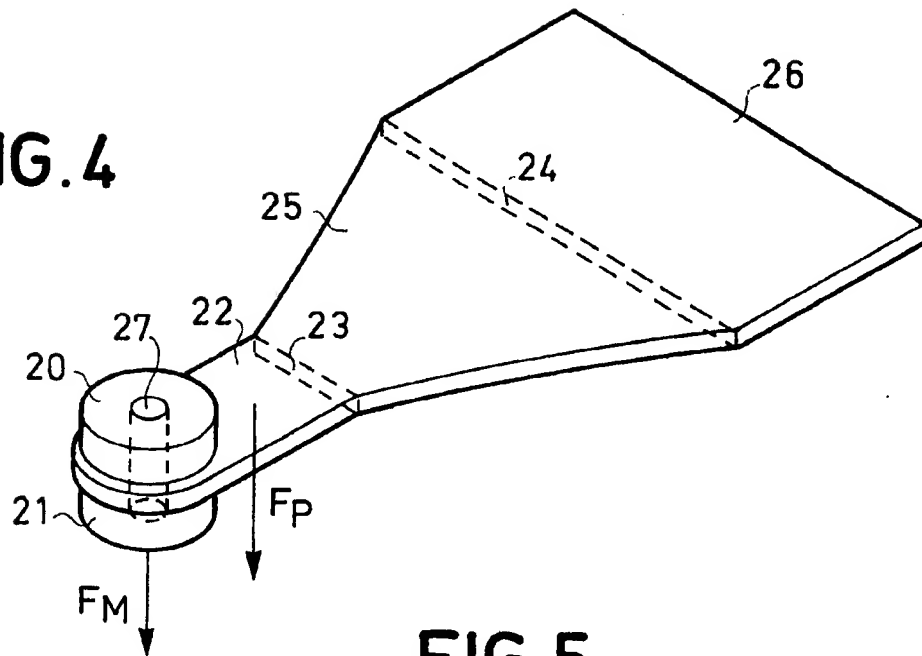


FIG. 5

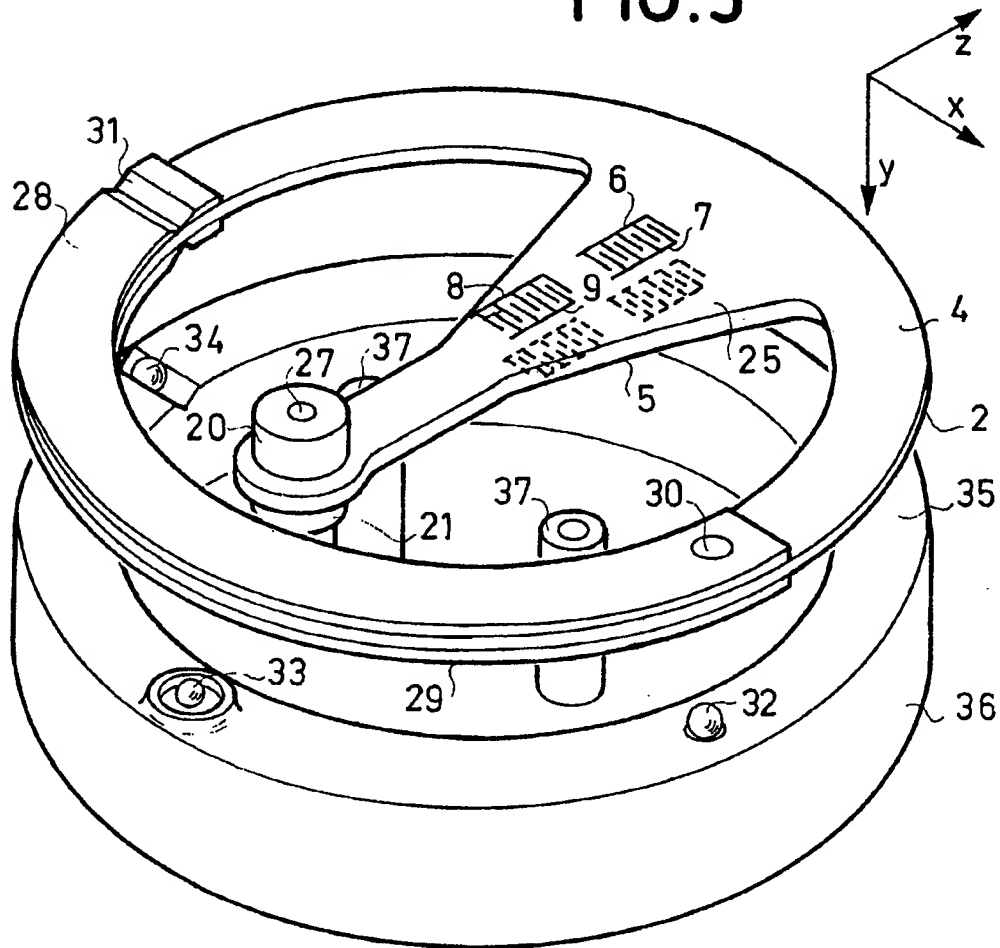


FIG. 6

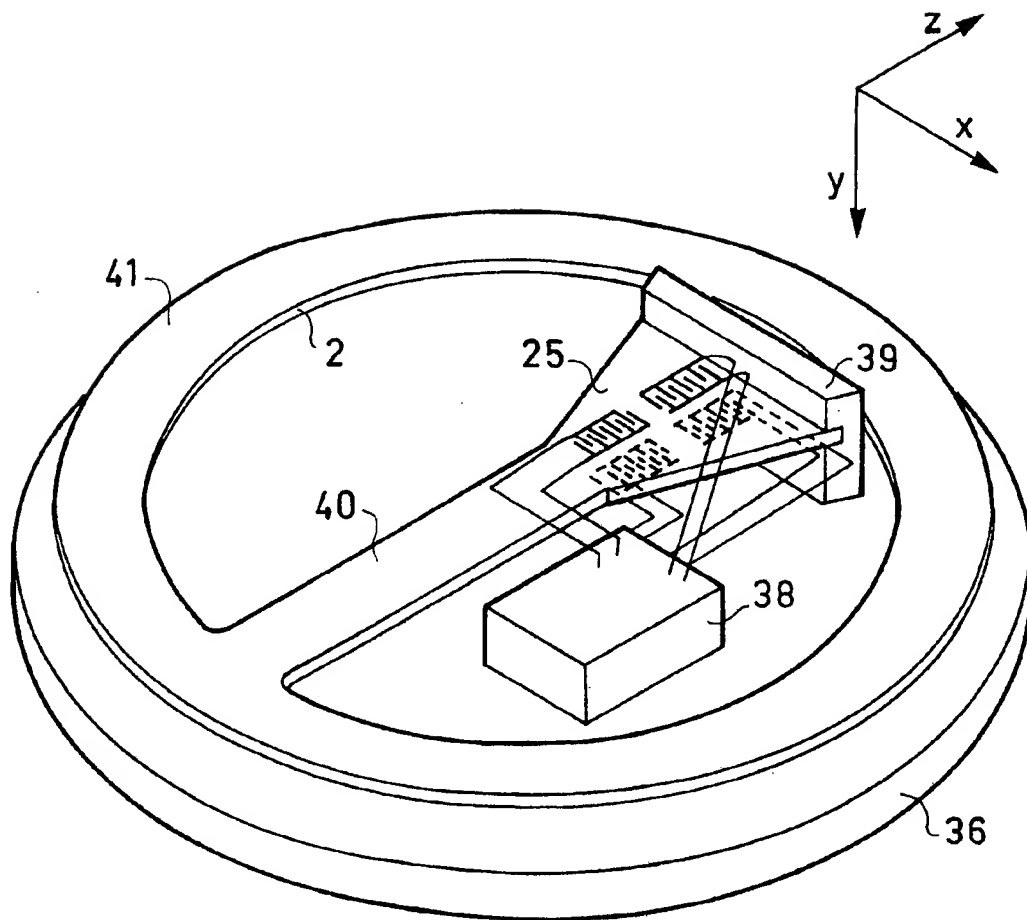


FIG. 7

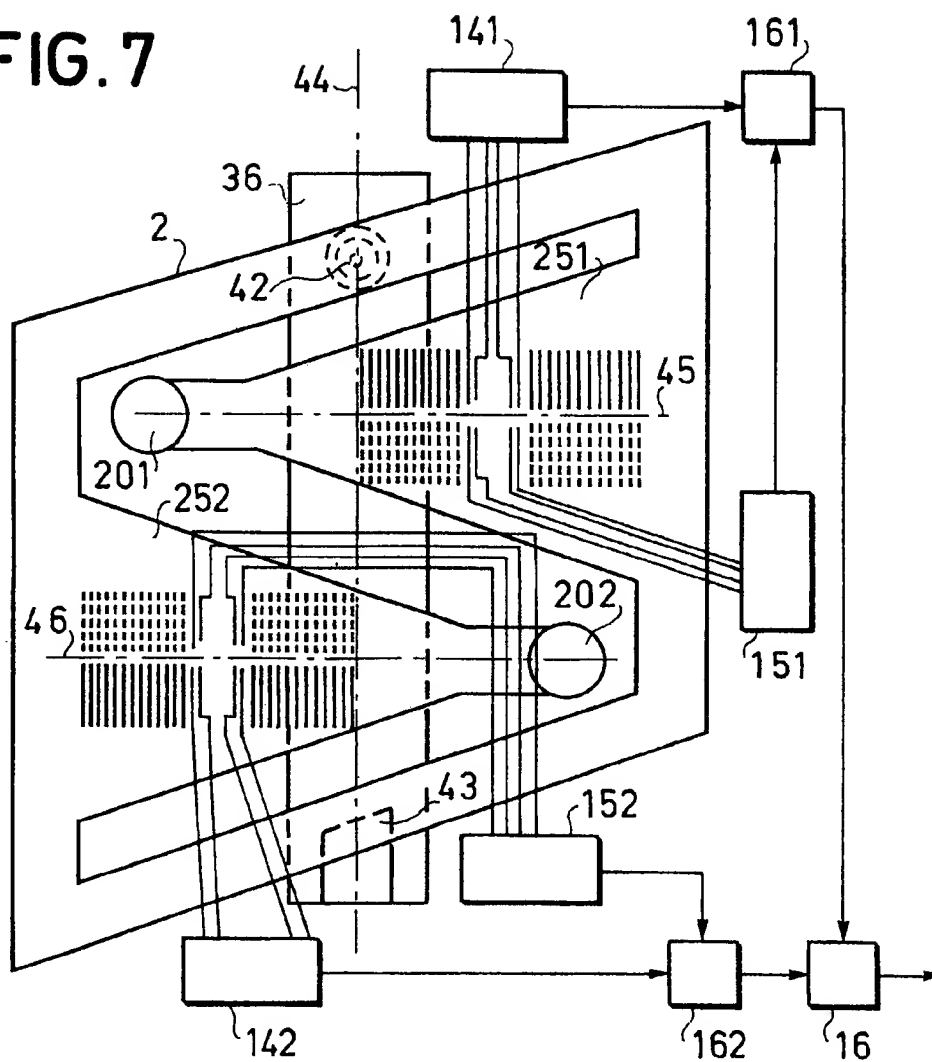
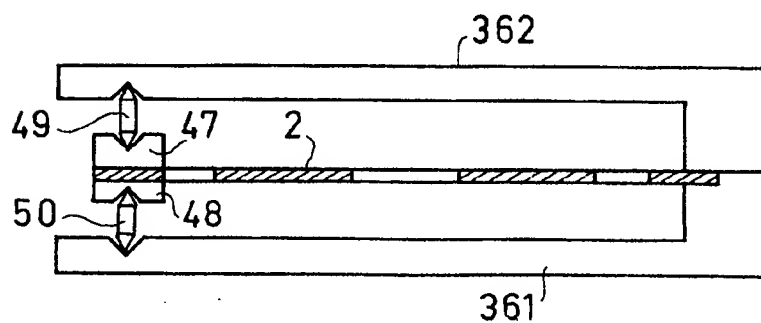


FIG. 8



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FIG. 9

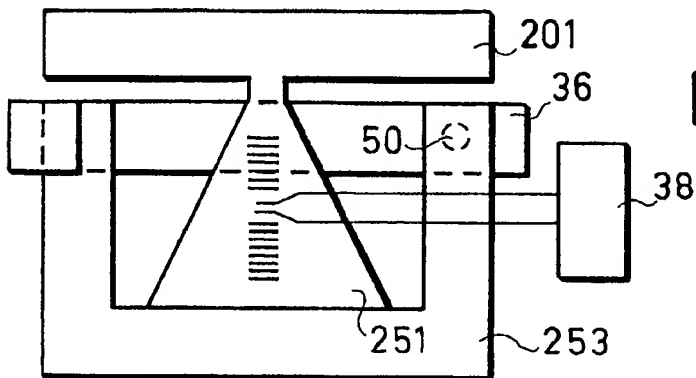
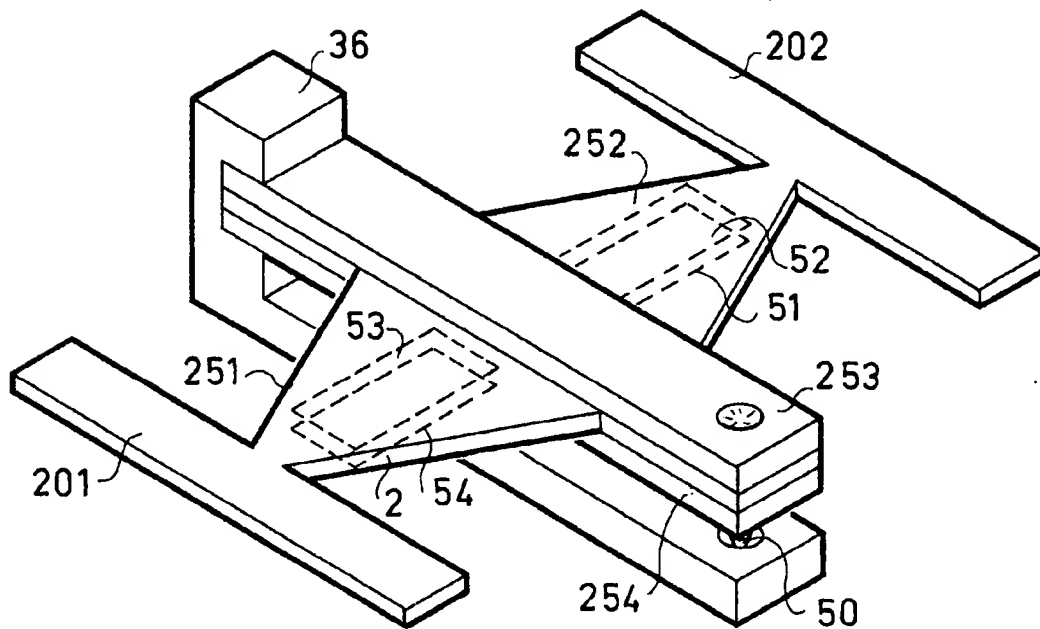
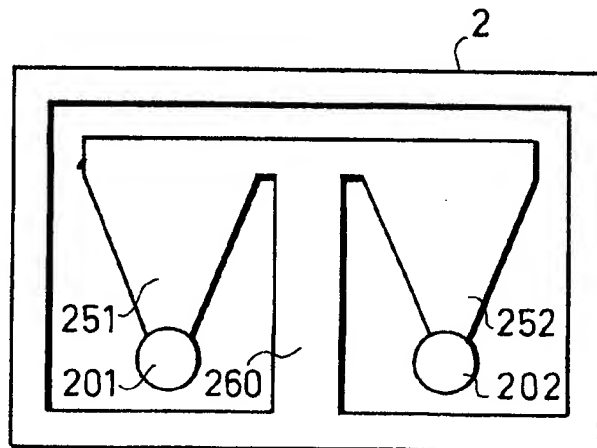


FIG. 10

FIG. 11



## SPECIFICATION

### Elastic surface wave accelerometers

#### Background of the invention

The present invention relates to elastic surface wave accelerometers and more particularly to those comprising at least two oscillators connected to transducer means situated on both faces of an elastic plate bending under the action of the acceleration. With such a structure the acceleration may be measured along a component of direction normal to the main faces of the plate, which generally has one end embedded in a frame and a free end where a seismic mass may be attached. The transducer means are designed for exciting and collecting elastic surface waves whose speed of propagation is known to vary as a function of the mechanical bending stresses. In a first embodiment, the transducer means form a transmission line whose delay time determines the phase-shift of an oscillating loop. In a second embodiment, the transducer means are situated in a resonating network cavity and are connected to means for sustaining the oscillation of the cavity. The frequency representative of the acceleration to be measured results from the subtraction of two oscillation frequencies which present thermal drifts which do not exactly counter-balance each other.

In fact, these thermal drifts result from stresses created by the embedded mounting of the plate and possibly by mounting of the seismic mass. These stresses may be added to the mechanical bending stresses when the zones where they originate are close to the region occupied by the elastic surface wave measuring means.

When the mechanical bending stresses are those of a beam with constant section, their intensity varies with the bending torque, which requires accurate positioning of the elastic surface wave measuring means. Furthermore, the variation of the stresses causes a variation of the speed of propagation of the elastic surface waves in the extent of the measuring zone, which may give rise to distortion of the wave fronts.

To palliate the above-mentioned drawbacks, the invention proposes using a plate with parallel faces cut so as to comprise a zone of equal resistance to bending in which the elastic surface wave measuring means are situated.

#### Summary of the invention

The invention provides an elastic surface wave accelerometer in which a plate with parallel faces bends under the action of the acceleration to be measured; the bending stresses created in said faces being detected by elastic surface wave measuring oscillator means, characterized in that said oscillator measuring means are situated in a zone of equal resistance to the bending of said plate.

The invention will be better understood from the following description and accompanying figures.

#### Brief description of the drawings

Figure 1 is an isometric view of an elastic surface wave accelerometer of a known type;

Figure 2 is an explanatory figure;

Figure 3 is an isometric view representing structures of equal resistance to bending equipped with elastic surface wave transducer means;

Figure 4 shows a plate for an accelerometer in accordance with the invention;

Figure 5 is a partial isometric view of an elastic surface wave accelerometer in accordance with the invention;

Figure 6 is an isometric view of a first variation of an accelerometer according to the invention;

Figure 7 is a top view of a second variation of an accelerometer according to the invention;

Figure 8 is an elevational view of the variation shown in Figure 7;

Figure 9 is a partial isometric view of a third variation of an accelerometer according to the invention; and

Figures 10 and 11 illustrate other embodiments of accelerometers in accordance with the invention.

#### Detailed description of the invention

In the following description, the mechanical bending stresses generated by the acceleration appear in the main faces of a plate of constant thickness cut out from a material capable of propagating elastic surface waves. By way of non limiting example, a plate may be used cut out from crystalline piezoelectric material such as quartz but, at the price of a more complex construction of the elastic surface wave transducer means, a silica plate may also be used. In so far as the measurement of the acceleration is concerned, it is the component along the normal to the main faces of the plate which is measured. The cut-out shapes envisaged are such that the rigidity to bending for forces acting parallel to the main faces of the plate is greater than the rigidity taken into account for measuring the normal component of the acceleration. The accelerometer necessarily comprises a plate support allowing bending thereof. The measuring mass may be formed by the plate itself or by a seismic mass. In this latter case, the plate forms a resilient connection between the support and the seismic mass and all the elements are assumed to undergo the same acceleration.

In Figure 1 can be seen, related to a trirectangular trihedron Oxyz, an elastic surface wave accelerometer of a known type. The acceleration to be measured  $\vec{p}$  whose direction is parallel to oy is applied to a support 1, to a seismic mass 3 and to a resilient plate 2 connecting support 1 to mass 3. The cross section of the plate corresponding to a section parallel to plane yox is rectangular of width b and height h. Its moment of inertia, when it bends under the action of the acceleration  $\vec{p}$ , is given by the expression  $b.h^3/12$  where h is substantially smaller than b. For a force applied along ox, the

moment of inertia is much higher and for a force along  $oz$  the bending is not taken into account.

The deformations of plate 2 are detected by elastic surface wave measuring means. If, for example, plate 2 is a quartz plate of cut ST which offers a zero thermal drift at a temperature of 25°C, the main faces 4 and 5 are provided with interdigitated comb electrodes 6, 7, 8, 9, 10, 11, 12, and 13 which define radiating gaps oriented along  $ox$ . Electrodes 6 and 7 form a transducer emitting elastic surface waves which progress in direction  $oz$  before being picked up by an electrode array 8 and 9 forming the reception transducer. The array of conducting elements carried by face 4 forms then an elastic surface wave delay line which serves as loop for an amplifier 14. The array of conducting elements carried by face 5 forms another elastic surface wave delay line relooping the input and the output of another amplifier 15. We have then a pair of oscillators whose oscillation frequencies  $f_1$  and  $f_2$  are related to the transit times  $t_1$  and  $t_2$  of the elastic surface waves exchanged along faces 4 and 5. The outputs of amplifiers 14 and 15 are connected to the inputs of a subtracting mixer 16 whose output 17 provides an alternating signal of frequency  $f = f_1 - f_2$ . So as not to overload the connection diagram, ground connections G have been added to the electric diagram of Figure 1.

In the presence of an acceleration  $\vec{y}$ , the simple bending of plates 2 causes the appearance of mechanical bending stresses at faces 4 and 5, which results in modifying in opposite directions the transit times  $t_1$  and  $t_2$ . This results in new oscillation frequencies  $f_1 + \Delta F$  and  $f_2 - \Delta F$  and a signal at output 17 having a frequency  $f + 2\Delta F$ . It can then be seen that the acceleration  $\vec{y}$  is measured by a frequency variation  $2\Delta F$ .

The deformation of plate 2 by simple bending also produces mechanical shearing stresses, but these are zero along the free faces 4 and 5 which convey the elastic surface waves. This is why the simple bending may be likened to pure bending. So as to avoid skew bending, plate 2 and mass 3 are given a shape having a plane of symmetry parallel to  $yo$ , thus the mechanical twisting stresses of plate 2 are avoided. On the other hand, with the arrangement of figure 1, parasite stresses may be added to the mechanical bending stresses because of the embedment of plate 2 in support 1 and in the seismic mass 3. The thermal expansion of plate 2 may present differences with respect to that of the grooves of support 1 and of the seismic mass 3, which may falsify the measurement of the acceleration. Furthermore, as shown in Figure 2, where the same references designate the same elements as in Figure 1, the bending moment in each cross section of plate 2 varies considerably. The straight line 18 represents the variation of the bending moment  $M$  along axis  $z$  for an end load  $\vec{F} = m\vec{y}$  a curve 19 gives the variation of the bending moment  $M$  resulting from the proper mass of the plate. The diagram of Figure 2 shows that the mechanical bending stress in the case of a plate with constant

moment of inertia section and constant thickness is a magnitude which varies substantially in the measuring region where the elastic surface waves are exchanged.

The variation of the mechanical stresses implies a corresponding variation of the propagation speed of the elastic surface waves. This may result in distortions which affect the wave fronts and the delayed electric signal. Furthermore, the position of the transducer means becomes critical since the sensitivity depends on the position of these means along the plate.

In Figure 3 can be seen two plates embedded in a support 1 which, in the plane  $xoy$ , have a profile which widens out gradually towards the embedment. In the case of a plate of constant thickness  $h$ , only the proper mass of which responds to the acceleration to be measured, an elastic bending stress of constant value is obtained when the deformed shape has a constant radius of curvature  $\rho$ . For a current value  $z_0$  of the spacing away of  $z$ , the elementary bending moments may be integrated which act on the plate cross section having the width  $b_0$  at the distance  $z_0$  from point O and height  $h$ . If  $M(z_0)$  is the resulting bending moment,

$$I = \frac{b_0 h^3}{12}$$

the moment of inertia of this cross section and E the modulus of elasticity of the material forming plate 2, we have the expression

$$\frac{1}{\rho} = \frac{M(z_0)}{E.I}$$

It can be seen that the condition of equal resistance is tantamount to adopting a rigidity to bending  $E.I$  proportion to the bending moment  $M(z_0)$ . The profile of plate 2 in plane  $xoz$  is defined by two arcs of a parabola as shown in Figure 3 in so far as the plate 2 occupying the second position is concerned. The interdigitated comb transducers 1, 7, 8 and 9 may be situated in the half of face 4 on the left of axis  $z$ , whereas the interdigitated transducers 10, 11, 12 and 13 are situated in the half of face 5 on the right of axis  $z$ . Such an arrangement with lateral offset is advantageous for reducing the capacitive coupling between the measuring means of face 4 and those of face 5. Figure 3 also shows in the first position a plate 2 whose condition of equal resistance to bending is provided by a triangular shape with apex O. This case corresponds to a plate whose proper mass may be neglected with respect to a seismic mass ( $m_0$ ) exerting at O the force of inertia  $\vec{F} = m_0 \vec{y}$  where  $\vec{y}$  is the acceleration to be measured. In the general case, the proper mass of the plate and the added mass define a profile of equal resistance to bending intermediate between the two types shown in Figure 3.

In Figure 4 is shown a plate 2 for an accelerometer according to the invention which comprises a median zone 25 of equal resistance to bending connecting together an embedment zone 26 having a cross section 24 of constant width and height and an end zone 22 with cross section 23. The end zone 22 has passing there-through a mounting pin 27 carrying two inertial blocks 20 and 21 which, because of the acceleration to be measured, exert a force  $\vec{F}_M$ . The end zone 22 exerts a force  $\vec{F}_p$ . The equal resistance condition applies from section 23 in which acts a bending moment which results from the forces  $\vec{F}_M$  and  $\vec{F}_p$ . All the cross sections of the zone of equal resistance 25 are dimensioned in width by taking into account the additional load due to the proper mass of the plate between section 23 and each of the intermediate sections as far as section 24. It will be confirmed in practice that the bending moment  $M$  which each cross section of the equal resistance zone must withstand varies in proportion to the moment of inertia of the section, i.e. in proportion to its width. The trend of the zone of equal resistance 25 is trapezoidal but the sides which connect together the bases are slightly curved as shown in Figure 4, if the proper mass of the plate must be taken into account.

The partial isometric view of Figure 5 shows one embodiment of an accelerometer using a piezoelectric plate with parallel faces 2 whose cut presents an equal bending resistance zone 25. The cut shown in Figure 5 comprises an annular frame connected inwardly to a measuring tongue comprising at its proximal end the equal resistance zone 25 and at its distal end an assembly of inertia blocks 20, 21, 27. Preferably the cut of plate 2 is symmetrical with respect to axis  $z$  which, in the case of Figure 5, is a diameter with respect to the outer circular contour of plate 2.

This particular arrangement is advantageous, for it allows the members for fixing plate 2 to be spaced apart from the measuring zone 25 which contains the elastic surface wave transducers carried by faces 4 and 5. With this spacing apart, the stresses may be attenuated which are due to the method of fixing plate 2 which is diametrically opposite the connection of the tongue with the annular frame. The bending, twisting and shearing stresses which arise in the annular frame because of the acceleration have little repercussion in zone 25. To reinforce the annular frame of plate 2, there may be provided, as shown in Figure 5, two stiffeners 28 and 29 in the form of arches which are applied or bonded to faces 4 and 5 of plate 2. These stiffeners 28 and 29 are advantageously cut from a plate identical to the one which served for forming plate 2 while taking care during assembly to keep the same crystallographic orientations. Thus the creation of stresses can be avoided which are due to differences of thermal expansion between elements 28, 29 and 2.

The set of elements 2, 28 and 29 forms an assembly which must be fixed to a half case 36

which may be made from a material having a thermal expansion coefficient different from the expansion coefficients proper to the material forming the assembly.

Thus, it is advantageous to adopt fixing means leaving the assembly free to expand in plane  $xy$  while being well seated on flange 35 of the half case 36. Figure 5 illustrates an advantageous embodiment based on a set of balls serving as intermediate support means. A ball 32 is positioned in two conical cups formed respectively in flange 35 and in stiffener 29. This fastening allows the case to pivot with respect to the assembly. A second ball 34 is positioned in two V grooves orientated preferably towards the housings of ball 32 and cut out respectively in flange 35 and in stiffener 29. This second fastening leaves the assembly free to expand but fixes its orientation in plane  $xy$ . A third ball 33 nipped between two flat bearing surfaces belonging respectively to flange 35 and to stiffener 29 finally ensures the stable seating of the assembly on the half case, while leaving the expansion of the assembly free. In Figure 5, there has been omitted another half case which overhangs the assembly 2, 28, 29. This other half case rests on the half case 36 through columns 37 and its flange is connected to stiffener 28 through balls similar to balls 32, 33 and 34. Figure 5 shows the V housing 31 and the conical housing 30 formed in stiffener 28 for receiving two of these three balls. Although Figure 5 shows an assembly with arch shaped stiffeners, they may be either omitted or they may completely cover the annular frame of plate 2.

Another embodiment of the accelerometer of the invention is shown in Figure 6. The case 36 carries via a bracket 39 a mobile assembly formed from a plate 2. The cut leaves existing a tongue 40 one end of which is connected to an annular frame 41 serving as seismic mass and whose other end beyond an equal bending resistance zone 25 is embedded in bracket 39. Assembly 38 contains the electric oscillator and mixer circuits which cooperate with the elastic surface wave measuring means situated in zone 25.

The advantageous arrangements illustrated in Figure 6 may be applied to Figure 5. Thus, the seismic masses 20, 21, 27 are added to plate 2 may be replaced by extensions of plate 2 which occupy the two recesses situated on each side of the central tongue. Similarly, the advantageous arrangements illustrated in Figure 5 may be applied to Figure 6, where bracket 39 could be replaced by a ball mounting holding imprisoned an inner open frame cut out from plate 2 from the end of zone 25. The two curved legs of this inner open frame occupy the two empty parts which surround the central tongue 40.

As was seen above, measuring the bending by elastic surface waves takes place in an equal bending resistance zone obtained by cutting a plate with parallel faces. The tongue obtained may be integrally formed with an open or closed frame which serves as means for mounting on a

case and its free end may comprise extensions which add mass to increase the sensitivity to the acceleration which it is desired to measure.

- The invention is not limited to a cut-out comprising a single measuring tongue, for the same frame may be common to several tongues each comprising a measuring zone of equal resistance to bending. In Figure 7, another embodiment of a measuring assembly 2 may be seen comprising within a frame in the form of parallelogram two measuring tongues each having a zone of equal resistance 251 and 252. Each tongue is cut-out symmetrically with respect to an axis 45 or 46 in an approximately trapezoidal shape which ends in a free end carrying a seismic mass 201 and 202. Each equal resistance zone 251 and 252 contains on the two faces of plate 2 an elastic surface wave measuring means. In the case of Figure 7, the measuring means used are elastic surface wave resonators. Each resonator comprises a cavity defined by two arrays of reflecting lines formed on the main faces of plate 2 by etching or by ionic implantation. Electrodes are photo-etched in the cavity of each resonator for maintaining with an amplifying circuit 141, 151, 152 or 142 standing elastic surface waves. Thus, in Figure 7, four oscillators are provided whose oscillation frequencies vary with the bending stresses generated by the acceleration to be measured. Supposing that the two measuring tongues of Figure 7 react in the same way to an acceleration perpendicular to the plane of the figure and assuming that the rest frequencies of oscillators 141, 142, 151 and 152 are respectively,  $f_1$ ,  $f_2$ ,  $f_3$ , and  $f_4$ , mixer 161 delivers the difference  $f_1 - f_3$  and mixer 162 the difference  $f_4 - f_2$ . A mixer 16 receives the signals coming from mixers 161 and 162 and delivers a signal whose frequency variation

$$f_1 + f_2 - f_3 - f_4$$

- represents the acceleration undergone by the assembly. In fact, if  $\Delta f$  is the frequency deviation which the acceleration produces, the oscillation frequencies are:  $f_1 + \Delta f$ ,  $f_2 + \Delta f$ ,  $f_3 - \Delta f$ ,  $f_4 - \Delta f$ , which gives at the output of mixer 16 a signal whose frequency is of the value

$$f_1 + f_2 - f_3 - f_4 + 4\Delta f.$$

- If  $\Delta F_1$ ,  $\Delta F_2$ ,  $\Delta F_3$  and  $\Delta F_4$  are the temperature drifts of the four oscillators, the thermally disturbed frequencies are  $f_1 + \Delta F_1$ ,  $f_2 + \Delta F_2$ ,  $f_3 + \Delta F_3$  and  $f_4 + \Delta F_4$ . The disturbed frequency at the output of mixer 16 will be:

$$f_1 + f_2 - f_3 - f_4 + \Delta F_1 + \Delta F_2 - \Delta F_3 - \Delta F_4.$$

- Thus, it can be arranged for the thermal drift:

$$\Delta F_1 + \Delta F_2 - \Delta F_3 - \Delta F_4$$

to be cancelled out more thoroughly than with

- two measuring oscillators. Mounting of the assembly of Figure 7 on the half case 36 may be made at two points in the middle of the sides of the frame which are not integrally formed with the measuring tongues. For this, an embedded support 43 and a pivoting support 42 are used.

- Figure 8 is a section along line 44 of Figure 7. Assembly 2 is clamped on the right between two half cases 361 and 362 but to complete the fixing, the left-hand part is supported between the two half cases 362 and 361 by pivot shafts 49 and 50 bearing between conical housings formed in the half cases 362 and 361 and in pivot blocks 47 and 48 which are fixed to assembly 2. Such a mounting system avoids to a great extent the stresses of thermal origin.

- In Figure 9, an accelerometer can be seen similar in design to that of Figures 7 and 8, but in which the measuring tongues are integrally formed with a central longitudinal member reinforced by two stiffeners 253 and 254. The seismic masses are formed by wings 201 and 202 formed directly during cutting out of plate 2. Zones 51, 52, 53 and 54 indicate the respective positions of the elastic surface wave measuring means which may be interdigitated comb delay lines or network resonators. These zones are of course included in the zones of equal resistance to bending of the two measuring tongues.

- Figure 10 shows another embodiment using a single measuring tongue forming the median leg of a cut-out in the shape of an E. The end of the measuring tongue comprises a wing 201 serving as seismic mass. The U shape which is integral with the zone of equal resistance 251 of the tongue is reinforced by bonding to each face a U shaped stiffener 253. The monobloc assembly thus formed is mounted in the same way as the one in Figures 7 and 8. Block 38 contains the oscillator and mixer circuits which cooperate with the elastic surface wave measuring means situated in zone 251.

- Figure 11 illustrates another cut-out shape of plate 2. Two measuring tongues 251 and 252 equipped with seismic masses 201 and 202 are integrally formed with a central tongue 260 which in turn is integral with a rectangular frame. By fixing the frame to the case of the accelerometer by means of the edge opposite the one which is integral with tongue 260, the influence of the fixing stresses is reduced to a maximum in the measuring zones 251 and 252.

#### 110 Claims

1. In an elastic surface wave accelerometer in which a plate with parallel faces bends under the action of the acceleration to be measured, the bending stresses created in said faces being detected by elastic surface wave oscillator measuring means, said oscillator means are situated in a zone of said plate having equal resistance to bending.

2. The accelerometer as claimed in claim 1, wherein said zone of equal resistance to bending belongs to a tongue having a free end and an end

for fixing it to a case undergoing the acceleration to be measured, the form of said tongue being symmetrical with respect to the bending plane which contains the measuring direction of the acceleration.

5 3. The accelerometer as claimed in claim 2, wherein said free end carries an added seismic mass.

4. The accelerometer as claimed in claim 2, 10 wherein said tongue is integrally formed with a frame which is connected to said case by connecting members ensuring positioning free of thermal stresses.

5. The accelerometer as claimed in claim 4, 15 wherein stiffening means cut out from the same material as said plate are applied or bonded to the parts of said frame requiring reinforcement.

6. The accelerometer as claimed in claim 4, 20 wherein said connecting members are balls, one of said balls being housed in a conical housing and another ball being housed in a V housing.

7. The accelerometer as claimed in claim 2, 25 wherein the free end of said tongue is integrally formed with elements of the plate forming a seismic mass.

8. The accelerometer as claimed in claim 7, wherein said elements form a frame.

9. The accelerometer as claimed in claim 7, wherein said elements form an aileron.

10. The accelerometer as claimed in claim 1, 30 wherein said plate forms an assembly with two measuring tongues each having a zone of equal resistance to bending.

11. The accelerometer as claimed in claim 10, 35 wherein said tongues are integrally formed with two opposite sides of a frame, the other two sides of said frame being intended to be connected to a case.

12. The accelerometer as claimed in claim 10, 40 wherein said tongues are integrally formed with a longitudinal member which serves as a suspension means for fixing to a case.

13. The accelerometer as claimed in claim 11, 45 wherein said longitudinal member is integrally formed with a frame.

14. The accelerometer as claimed in claim 10, wherein four elastic surface wave measuring oscillators are provided, first mixer means 50 subtracting two by two the oscillation frequencies of the signals produced by said oscillators and second mixer means subtracting the frequencies of the signals coming from said first mixers.

15. The accelerometer as claimed in claim 1, wherein said plate is piezoelectric.

16. The accelerometer as claimed in claim 1, 55 wherein said oscillator means comprise elastic surface wave tuning means of the delay line or reflecting network resonator type.

17. The accelerometer as claimed in claim 16, 60 wherein said tuning means carried by the faces of said plate are offset laterally in opposite direction with respect to the bending plane of said zone of equal resistance to bending.

18. An accelerometer substantially as 65 hereinbefore described with reference to and as shown in Figure 3 of the accompanying drawings.

19. An accelerometer substantially as hereinbefore described with reference to and as 70 shown in Figure 4 of the accompanying drawings.

20. An accelerometer substantially as hereinbefore described with reference to and as 75 shown in Figure 5 of the accompanying drawings.

21. An accelerometer substantially as hereinbefore described with reference to and as 80 shown in Figure 6 of the accompanying drawings.

22. An accelerometer substantially as hereinbefore described with reference to and as 85 shown in Figure 7 and 8 of the accompanying drawings.

23. An accelerometer substantially as hereinbefore described with reference to and as 90 shown in Figure 9 of the accompanying drawings.

24. An accelerometer substantially as hereinbefore described with reference to and as 95 shown in Figure 10 of the accompanying drawings.

25. An accelerometer substantially as hereinbefore described with reference to and as 100 shown in Figure 11 of the accompanying drawings.